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Seeking serpents: Ball python trade in Benin, West Africa

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Abstract

Ball pythons are traded as bushmeat, leather and belief-based medicine in West Africa, and specimens are exported in large numbers for the exotic pet trade. Here, we focused on understanding the purpose and socio-economic context of this trade in Benin through interviews with 44 actors involved in the trade of this species. We provided a snapshot of trade dynamics during a period when hunters are not predominantly actively involved in supplying eggs, neonates and gravid females for ranching and export as exotic pets. Our findings revealed that hunters and traders were largely focused on supplying the bushmeat and medicine markets in West Africa during this time. We estimated that the 21 collectors engaged in hunting in our study collectively hunt between 576 and 5,083 ball pythons from the wild each year. Collection rates reported by some suggests that they could earn more than 15,000 USD from ball python sales in bushmeat markets annually. Ball pythons hunted in Benin were mainly sold to local customers as "bushmeat" (53%) or for belief-based uses (39%) (including "fetish", "medicinal products" and "voodoo").

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However, cross-border trade with neighboring countries of Togo, Nigeria, and Ghana (or even further) also occurred. Although profitable for some, the scale of this practice, together with the widely reported decline in ball python populations in Benin, raises concern about the sustainability and long-term economic viability of this type of large-scale commercial wildlife trade in West Africa, especially as it occurs alongside extensive ranching practices to support the exotic pet trade.

Keywords
bushmeat, conservation, *Python regius*, ranching, snake, traditional medicine, wildlife trade

Introduction

Recent research has highlighted that ball pythons (*Python regius*) are globally popular exotic pets that are annually exported in large numbers from their native range in West Africa to meet high international demand in the US, Europe and Asia, with an even more substantial trade in the past (Harrington et al. 2020). Listed on Appendix II on CITES, relating to species for which trade is permitted, but regulated, to avoid utilization incompatible with their survival, the ball python is the single most traded CITES-listed live animal legally exported from Africa (D'Cruze et al. 2020a). Since the early 1980's, more than three million live ball pythons have been exported from West Africa, with total annual exports from Ghana, Togo and Benin averaging 100,000 since 2007 (Harrington et al. 2020). Yet, besides international demand for the exotic pet industry, in West Africa there is also a thriving domestic demand for ball pythons as bushmeat, leather and for use in belief-based medicine (Segniagbeto et al. 2013; Moshoeu 2017; D'Cruze et al. 2020c, 2021; Boakye et al. 2021).

Belief-based use of wildlife has been of cultural importance for many communities across Africa for millennia (Alves and Rosa 2013; Whiting et al. 2013; Atuo et al. 2015; Ezenwa et al. 2019; Loko et al. 2019; Assou et al. 2021). In West Africa, a wide range of animals are used by traditional healers and indigenous populations for various medical and magical-religious purposes, such as to ward against evil, for attraction, or to find love (Loko et al. 2019; Assou et al. 2021). Pythons (*Python* spp.), for example, are often sought to bring protection against witchcraft (D'Cruze et al. 2020c). It is reported that belief-based healers are widely consulted in many African countries because they are more accessible compared to university-trained medical doctors, particularly in rural areas (Williams 2007; Williams and Whiting 2016). In some communities across West Africa, larger numbers of ball pythons have been reported in sacred areas, which are thought to be a result of local rules and taboos that have likely benefited wildlife conservation (Toudonou 2015). In comparison, to the best of our knowledge, no scientific papers have been published explicitly about the extent and impacts of local demands for ball pythons in West Africa. Only a few studies so far point to the species within the bushmeat trade (e.g., Akani et al. 1998; Harwood 2003; Eniang et al. 2006; Eniang and Ijeomah 2011; Toudonou 2015).

Native to West Africa and northern parts of central and eastern Africa, ball pythons occur in a wide range of habitats, including grasslands, open woodlands, rainforest margins, forest/plantation mosaics, and agricultural land, from Senegal to southeastern Sudan and northwestern Uganda (Chippaux and Jackson 2019). They are a predominantly crepuscular and nocturnal species and are typically hunted during the day when they are resting in abandoned burrows, termite mounds, or beneath vegetation (D'Cruze et al. 2020a). Hunters in West Africa are known to collect eggs, neonates and gravid females from the wild to supply juvenile pythons for commercial export as pets (Harrington et al. 2020). Gravid females are reportedly kept by the hunters themselves, probably very rarely the case, or mostly at snake farms until the eggs are laid, before being released back into the wild, while egg clutches are typically sold directly to the farms (D'Cruze et al. 2020a). However, for the belief-based use and bushmeat trade in Benin adults of both sexes are collected (Toudonou pers. obs., 2021). Toudonou (2015) has previously described the illegal link between different ball python markets in Benin. For example, he reported that gravid females used in ranching systems are regularly sold into bushmeat markets instead of being released into the wild.

Ball python hunting and trade can play a substantial and important role in local livelihoods, providing economic opportunities for rural and urban communities in West Africa (D'Cruze et al. 2020a). However, unsustainable harvesting can have negative impacts on snake populations in the wild and long-term local livelihoods, challenging biodiversity conservation (Janssen 2021). For example, while most ball pythons traded internationally are reportedly produced via ranching operations [(Ineich 2006; Harrington et al. 2020), and also refer to the CITES trade database (https://trade.cites.org)], there are concerns that current hunting practices for maintaining ranch stock are negatively impacting wild populations (D'Cruze et al. 2020a). Hunters typically target the most vulnerable biological stages (i.e., gravid females and very young juveniles) and use destructive practices for wild ball python collection such as the digging and destruction of its burrows (D'Cruze et al. 2020a). There is also evidence that regulatory hunter oversight is lacking, yet it is required under national management plans and CITES, specifically (1) regarding the release of females after they have laid their eggs, (2) the release of 20% of the juveniles produced, or (3) the collection of adult males within quotas for wild-caught specimens (D'Cruze et al. 2020a). In addition, there is no monitoring unit/body to ensure the release of females/juveniles takes place back at their location of capture.

A recent genetic analysis of wild ball pythons has also indicated that the largely unregulated wild release component of the python production process in West Africa [e.g., snakes being released without full consideration of key aspects such as source location and the habitat of release sites (D'Cruze et al. 2020a)] is resulting in genetic modifications that could have long-term implications on the conservation of wild populations (Auliya et al. 2020). A range of potentially pathogenic bacteria of various genera have also been found on pythons maintained at registered farms (D'Cruze et al. 2020d; Bates 2021), that if released back into wild populations as part of the ranching

system could pose a risk of infectious disease transmission with potential impacts on the health of remaining wild ball python populations (D'Cruze et al. 2020b).

Regional declines in wild ball python populations have been reported in most West African range states (Penner et al. 2008; Reading et al. 2010; Toudonou 2015; D'Cruze et al. 2021), with high offtake levels and exploitation for the international pet trade (D'Cruze et al. 2020a) cited as a primary threat (D'Cruze et al. 2021). Population declines have also been widely reported among hunters in Togo (D'Cruze et al. 2020a), which calls into question the sustainability of this trade. Due to the persistent high level of exploitation across its core area of distribution and concerns about its long-term survival in West Africa, the ball python was evaluated as Near Threatened on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species in 2021 (D'Cruze et al. 2021).

To develop effective strategies to mitigate the potential threats posed to ball pythons by trade, it is imperative to understand the dynamics and drivers of all types of trade (for all significant 'uses' of the species) and its potential implications. However, the last review of ball python hunters and their experiences in Benin was carried out 15 years ago in a very brief time frame (Ineich 2006) and is likely outdated due to the dynamic nature of wildlife trade (Challender et al. 2015), and anthropogenically induced land use changes (CILSS 2016). Recent studies have documented ball python hunting (D'Cruze et al. 2020a) and production systems for the international pet market in Togo (Harrington et al. 2020). Here we focus on understanding the purpose and socio-economic context of this trade in Benin through interviews with 44 actors involved in the overall trade of ball pythons. Hunting activity to supply eggs, neonates, and gravid females to ranching operations (for international export) in Benin typically occurs between November and February when these life stages are naturally most abundant in the wild (Toudonou pers. obs. 2021). Interviews were conducted from July to October 2020, outside of the active period of hunting for ranching as a "snap-shot" to better understand the dynamics, drivers, and impacts associated with the overall trade of ball pythons (and thus to capture a more complete picture of the year-round hunting pressure on this species). Specifically, we sought to (1) characterize the different actors involved in the ball python trade in Benin and the dynamics of the trade, (2) identify the nature of consumer demand next to and outside the active international pet trade hunting season, and (3) identify trader perceptions about the current status of wild ball python populations.

Methods

Study area

The Republic of Benin is a West African country located between 6°10'N–12°25'N and 0°45'E–3°55'E. The country is bordered by Togo in the West, Nigeria in the East, Burkina Faso and Niger in the North, and the Atlantic Ocean in the South. In 2021,

the population of Benin was estimated at approximately 12.5 million (World Population Review 2021). Most people live within a highly concentrated 100 km strip in the south of the country (INSAE 2015). Two main geographically distributed sociocultural groups of the following tribes can be distinguished; northern Benin: the Bariba, the Dendi, the Bètamaribè, the Yoa Lokpa and the Fulani; and in southern Benin: the Adja, the Fon and the Yoruba (INSAE 2004; Lewis et al. 2016). Christianity is the largest religion practiced in Benin (48.5% of the population) followed by Islam (27.7%) and Vodun (11.6%). Around 12% of the population have no religion or are part of other traditional local religious groups (World Population Review 2021). Vodun (Fon language meaning "ghost") is believed to originate from Benin (Durand-Barthez 2002) and is relatively widespread among the population. Many individuals who nominally identify themselves as Christians or Muslims also practice traditional local religious beliefs, and it is not unusual for members of the same family to practice Christianity, Islam, traditional local religious beliefs, or a combination of all of these (Barbier and Dorier-Apprill 2002).

More than 70% of Benin's population is economically dependent on agriculture (Benin is Africa's largest cotton producer), and agricultural areas occupy around 27% of the country's total land cover (USGS 2021). Other major agricultural products include cereals (e.g., maize, groundnut, peanut, bean), roots (e.g., sweet potato and cassava), tuber (e.g., yam, potato), palm nut, cashew, and pineapple. Areas typified by these crops constitute generally suitable habitats for ball pythons because (1) these are not extensive monocultures but rather home gardens with other weeds interspersed, (2) the soil texture is soft due to regular working, and (3) rodent populations are attracted by crop yields. The only exception might be cotton fields which are also regularly exposed to intensive pesticide applications.

Benin has a hot and humid climate with a bimodal rainfall regime in the south and a unimodal rainfall regime in the northern part of the country. In the south, a long, wet season occurs from April to July and a short, wet season from September to November. The annual rainfall varies from 900 mm to 1300 mm (Ahokpossi 2018). In the north of Benin, the climate is characterized by one wet season and one dry season. Under climate change predictions, stronger warming and a much wider range of precipitation uncertainty is expected, with increases in the intensity of both dry and wet seasons (Sylla et al. 2016).

According to USGS (2021), Benin is characterized by a diversity of landscapes and ecosystems. The semi-arid grassland ecosystems in the north are considered the most biodiverse found in West Africa in terms of plant species (USGS 2021). The central part of the country is covered by a mosaic of different types of savannahs, gallery forests, woodlands, and croplands. In the south, the landscape is characterized by agricultural areas scattered with palm groves and small patches of forest remnants. However, savannah types remain the dominant land cover type in Benin, although considerably fragmented due to agricultural expansion, they cover more than half of the country and range from open tree savannahs in the north to wooded savannahs in the south. A century ago, much of southern Benin was covered by dense, biologically diverse lowland forests. Nearly all of this forest cover has since been lost, with the remaining original dense forest now occupying only 0.2% of total land cover (USGS 2021).

Data collection

A preliminary scoping survey was carried out from July to September 2007 in four villages (Kpomassè, Houègbo, Toffo, Djidja) of the two provinces, the Atlantique and Zou, in the south of Benin (Fig. 1). Interviews conducted within communities at that time established that both provinces are intensively involved in the ball python harvest. In addition, another three villages in southern Benin [Lanta (Couffo province), Houéyogbé (Mono province), Sô-kpota (Zou province), Fig. 1] where ball python harvest rates are low were also visited. Interviews with ball python hunters and traders during this preliminary survey confirmed that commercial capture of pythons was concentrated in all areas of southern Benin, except the Littoral province on the southern coast, where the harvesting of ball pythons was reportedly limited to only a few districts because of low harvest rates within the last one to two years (Toudononou pers. obs. 2021). According to Ineich (2006) and information provided by the Benin forestry authority in 2009, there were reportedly 11 authorized ball python exporters in Benin.

Our subsequent comparative survey, conducted in 2020, focused on all localities that were identified in the scoping interviews as targeted by python hunters, including locations where snakes [including pythons i.e., Northern African rock python (*Python sebae*) and *P. regius*, puff adders (*Bitis arietans*) and cobras (*Naja* spp.)] were commercialized for belief-based use and bushmeat. All villages visited during the survey are distributed within the Guineo-Congolian region and Guineo-Sudanian transition zone (Fig. 1) and represent 16.1% of the national area (INSAE 2015).

Interviews

Survey interviews with people involved in the ball python trade were conducted by the lead author and local field staff between July and October 2020 (which is outside of the typical hunting for ranching season). Interviews were conducted in French and, when needed, translated into the local language by field assistants, who were always resident in the village being surveyed. Before beginning any survey activity in an area, field staff met and introduced themselves to local officials (e.g., traditional chiefs, kings, village/quarter chiefs) to obtain their agreement, support, and protection. Interviewees were selected through a process of chain referral, whereby participants or other individuals (such as local leaders) recommended other potential participants to take part (for example some snake meat sellers recommended snake hunters). This snowball sampling approach ensured that participants who could provide information pertinent to the study were selected as representatives of the ball python trading community. A total of 44 individual structured interviews were conducted. In addition, group discussions were encouraged to gather information on local snake uses, sacred species, local names, sacralisation stories, bans and punishments. The survey sample was composed of individuals from a range of socio-economic backgrounds (e.g., farmers, ox herders, fishermen, traditional healers, forest guards and foresters, health workers, staff of the public sector, policemen, reptile collectors, reptile breeders/exporters,

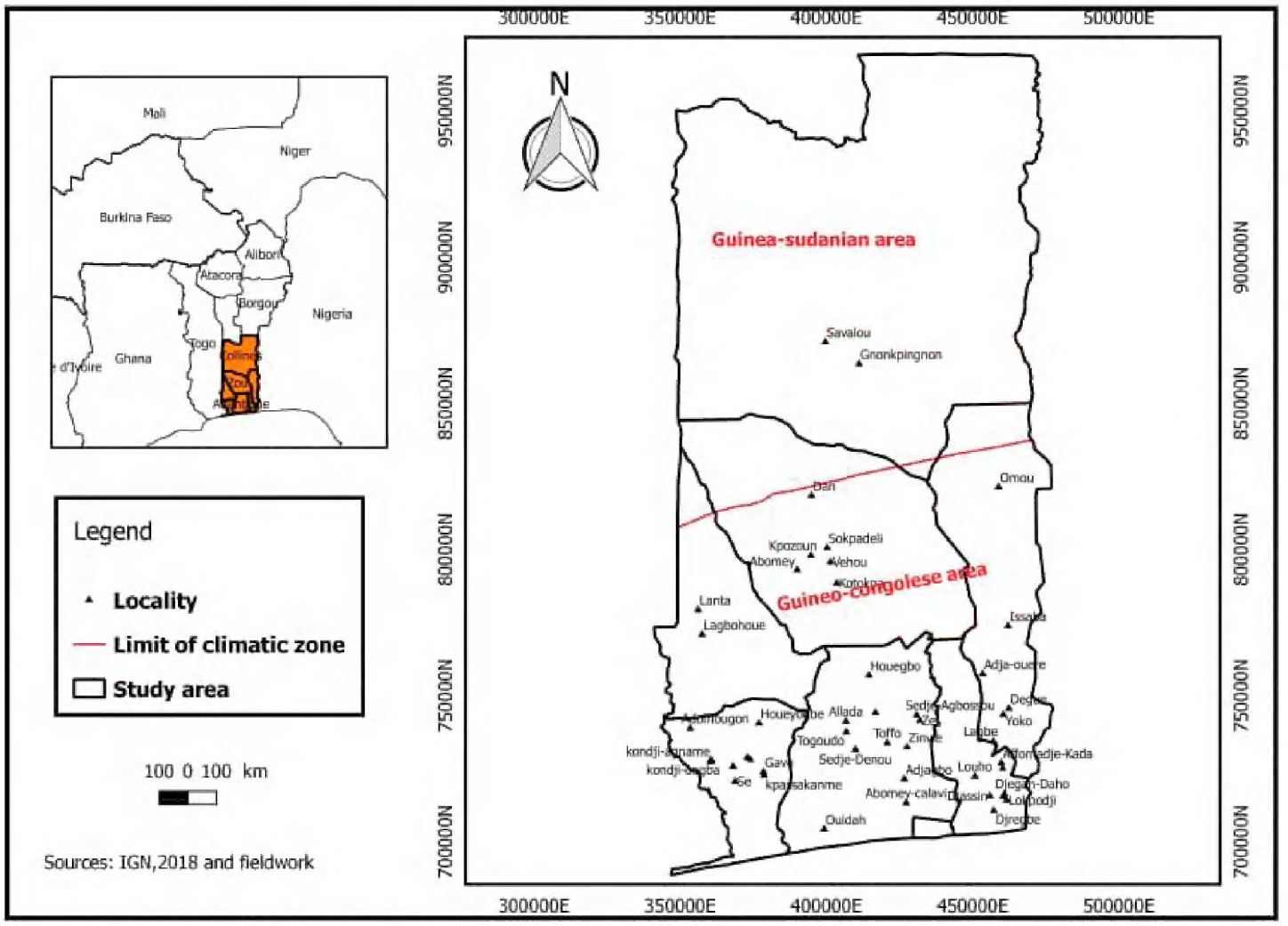

Figure 1. Map showing survey locations where snakes were collected and sold; inset above left shows the southern part of Benin in relation to the rest of the country and bordering countries. Locality refers to the villages surveyed in this study. Climatic zones are broadly deliniated.

teachers, animal fetish sellers, fish/bushmeat sellers), and various socio-cultural groups (i.e., kings, religious chiefs, traditional cult worshippers, sacred forests guards and other members of the community).

Each interview included 43 questions that were either open-ended (participants expressed their response in their own words), or a combination of open-ended and closed form [(multiple choice, but with the opportunity to add comments or additional categories); see Suppl. material 1]. The interview was structured by three themes: (1) demographic information i.e., age, gender, regional province, district, village, profession, education level, literacy level, ethnic group, religion, marital status, languages spoken and written, social status, (2) general information on snakes and the trade in ball pythons i.e., position of interviewee in trade chain, reason for involvement in the trade, knowledge about ecological role(s) of python/snakes, and (3) perceptions about the benefits of the python trade, sustainability, the species abundance and trade prices (see Suppl. material 1). We did not ask specifically in what form ball pythons were bought and sold but note that they may have been alive, dried, or smoked and either whole or in part. Each interview lasted between 20–35 minutes.

In accordance with the British Sociological Association Statement of Ethical Practice (BSA 2017), informed consent was obtained verbally from every survey participant prior

to the interview, the objectives of the study were explained to participants, and they were made aware of their rights to voluntarily participate or to decline. Names of people, and names and/or precise locations of households, were not asked for or recorded.

Data analysis

All analyses were carried out in R version 4.02.00 (R Core Team 2020). Descriptive statistics were calculated for the survey responses, and Fishers' exact tests and Chi-squared tests of association were used to test for associations between responses to survey questions. A Kruskal-Wallis nonparametric test was used to test for statistical differences between the median prices paid per snake at point of sale (price bought for, price sold for at bushmeat markets, price sold for to other buyers). All interviews were included in the analyses even if they contained missing data. The survey was conducted with 44 participants in total but most did not provide an answer to every question and this is reflected in the variable sample number presented in the results section. To visualize data with multiple categories we used word clouds, where font size is proportional to the number of participants. Word clouds were produced using the R package 'wordcloud' (Fellows 2018). Wildlife trade dynamics even at local scales can be complex but for simplicity and because our sample size is rather limited, we have attempted to describe participant actions, and features of the ball python trade (such as where it takes place, for what price, etc.), according to specific participant roles within the trade.

Monetary values were reported in West African CFA Francs (CFA) and converted to US dollars (USD) using 1 CFA = 0.0018 USD (conversion rate as of 10.09.21, xe.com). The following variables and equations were defined to describe the extent and magnitude of the ball python trade:

Average number of ball pythons hunted annually per hunter = number* of snakes hunted per hunting trip × number of 'snake hunting' days per year [Definition 1] (range = minimum and maximum number of snakes hunted per hunting trip × number of 'snake hunting' days per year).

Average number of ball pythons hunted annually in total = sum of (number of snakes hunted per hunting trip × number of 'snake hunting' days per year) [Definition 2] (range = sum of (minimum and maximum number of snakes hunted per hunting trip × number of 'snake hunting' days per year).

Average number of ball pythons purchased annually per hunter = number* of snakes purchased per buying trip × number of buying days per year [Definition 3] (range = minimum and maximum number of ball pythons purchased per buying trip × number of buying days per year).

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* where only a range of values was reported, we used the mid-point of the range to estimate 'average values'.

Average number of ball pythons sold at bushmeat markets annually per hunter = number* of snakes sold at markets per day × number of days that snakes were sold at markets per year [Definition 4] (range = minimum and maximum number of snakes sold at markets per day × number of days that snakes were sold at markets per year).

Average number of ball pythons sold to other buyers annually per hunter = number* of snakes sold to other buyers per day × number of days selling to other buyers per year [Definition 5] (range = minimum and maximum number of snakes sold to other buyers per day × number of days that snakes were sold to other buyers per year).

Results

Participant demographics

In 2020, interviews [lasting approx. 0.34 hrs. SD = 0.07] were conducted with 44 people from 30 villages located in four provinces in southern Benin (Atlantique, Mono, Plateau, Zou), who were involved in hunting and trading ball pythons (Fig. 1). The majority (82%; n = 36) of participants were male, 18% (n = 8) were female. The mean age of participants was 38 years (SD = 10.25). The most frequently reported ethnicity was Fon (48%; n = 21), followed by Nagot (16%; n = 7), and Yoruba (11%; n = 5). The remainder (25%; n = 11) stated a range of responses regarding ethnicity including Adja, Aïzo, Goun, and Tori. Most participants (82%; n = 36) were married and described themselves as "non-literate" (50%; n = 22). Around a third (27%; n = 12) reported being educated to secondary school level education, 12% (n = 5) to primary school level, and 43% (n = 19) reported having no education. The remainder either did not respond (9%; n = 5) or had professional training of some kind (7%; n = 3). Participants spoke a range of languages/dialects including Fon (48%; n = 21), French (36%; n = 16), Nagot (30%; n = 13), Yoruba (18%; n = 8), Goun (14%; n = 6) and Adja (9%; n = 4). Two thirds (59%; n = 26) reported themselves as being the head of their household. There was a significant association between gender and position in the household ($X^2 = 12.73$, df = 1, $p > 0.001$); 33% of females reported being head of their household, whereas 75% of males reported being head of the household.

Participants' roles in the trade

In terms of participants' roles in the ball python trade, 41% (n = 18) described themselves as being a ball python "hunter", a third (33%; n = 14) described themselves as being a "bushmeat seller", 18% (n = 8) described themselves as being a "middleman" in the trade chain, and two participants (7%) described themselves as an "exporter" (see Table 1 for role descriptions). Two participants reported holding multiple roles (one being both a "hunter" and a "bushmeat seller", and the other being a "hunter", "middleman" and "exporter"). Chi-squared test of association revealed no significant

Table 1. Definitions of ball python trade roles.

Trade role	Description	Number surveyed in this study
Hunter (sometimes referred to locally as a "collector")	A person who directly hunts ball pythons from the wild and does not source them from other people involved in the trade.	18
Middleman (sometimes referred to locally as an "intermediate" or "wholesaler")	Small-scale and large-scale traders. The quantities/numbers of specimens vary among them, with those often referred to as "wholesalers" trading the highest volumes.	8
Exporter	A person who owns a reptile facility and exports specimens either sourced from the wild and ranched (as for *P. regius*) or described as captive-bred, but also purchases eggs incubated and hatched inside the facility, as well as neonates and gravid females from hunters for the international exotic pet trade.	2
Bushmeat seller	A person who purchases ball pythons from all actors, mainly exporters, middlemen and hunters, and rarely engages in hunting snakes and sells them as food.	14

association between "position in the snake trade" and education level, gender, or province lived in. Other actors that we did not interview in this study facilitate the trade (for example, by providing transport logistics) but do not hunt, buy, or sell ball pythons.

When asked about how they source ball pythons (i.e., from hunting or buying), 42 people responded. Approximately two thirds (60%; n = 25) stated that they only hunt ball pythons, a third (33%; n = 14) stated that they only buy ball pythons from other sellers involved in the trade (in all cases the nature of the seller was unknown), and three participants reported engaging in both hunting and buying. Note that, throughout, the hunting and buying categories were not mutually exclusive so reported percentages can equal greater than 100.

Of the 16 participants who responded that self-described as primarily being a "hunter" in the trade chain, all stated that they only sourced ball pythons by hunting (i.e., they did not buy them). Almost a half (46%; n = 6/13) of the "bushmeat sellers" stated that they source ball pythons by hunting only, and over a third (36%; n = 5/13) reported only buying them from other sellers (two "bushmeat sellers" that responded engaged in both hunting and buying). Of those that self-described as a "middleman", the majority of those that responded (75%; n = 6) reported only buying ball pythons from other sellers and two stated that they only source ball pythons by hunting. The two "exporters" stated that they only buy ball pythons (i.e., they did not hunt them), and of the two participants that self-described as having multiple roles in the trade, both sourced ball pythons by hunting and buying.

When asked about how they sell their stock of ball pythons, 38 people responded. Just under two thirds (63%; n = 24) reported selling ball pythons at bushmeat markets (either alive and/or dried or smoked specimens), and 45% (n = 17) reported selling ball pythons alive to other buyers involved in the trade. Two participants reported selling ball pythons both at bushmeat markets and to other buyers. Across the 19 traders that sold to other buyers, the nature of the buyer was unknown for 89% (n = 17), one buyer was reportedly a "traditional healer", and one was both a "traditional healer"

and "bushmeat seller". Although the exact nature of most of these "other buyers" is unknown, four of the unknown buyers (24%) reportedly purchased ball pythons for "medicinal use" and one bought them for "food".

Of those that self-described as a ball python "hunter", just over half of those who answered (56%; n = 9/16) stated that they only sold ball pythons to other buyers (including seven of an unknown nature, one "traditional healer" and one "traditional healer and bushmeat seller") and 38% (n = 6) only sold ball pythons at bushmeat markets. Most "middlemen" who responded (80%; n = 4/5) reported selling ball pythons at bushmeat markets, and two sold to other buyers involved in the trade. Two thirds of the "bushmeat sellers" who responded (69%; n = 9/13) reported selling ball pythons at bushmeat markets, and 38% (n = 5/13) sold them to other buyers. The four participants that self-described as either "exporters" (n = 2) or having multiple roles (n = 2) reported selling ball pythons at bushmeat markets and not to other buyers.

When asked how they came to be involved in the ball python trade, 42 people responded. Over half of participants (55%; n = 23) stated that this was a result of their own "personal initiative", 26% (n = 11) reported that this was a result of their heritage as a "family trade", and the remaining participants (19%; n = 8) stated that they had followed the "advice" of others. When asked what they viewed their profession to be, 41 people responded. A third (33%; n = 15) reported their profession to be a "farmer", but a range of other diverse professions were also reported including "food seller", "traditional healer", "hairdresser", "mechanic", "priest", and "taxi driver" (Fig. 2A).

When asked about their role as an income generator in their household, 43 people responded. Three quarters (75%; n = 32) self-described as being a second- or third-income generator, and a quarter (25%; n = 11) reported being the primary income generator of their household. Both "exporters" reported being a primary income generator. There was a significant association between participants' position in the ball python trade and their position as income generator in their household (Fisher's exact test: p = 0.041); "middlemen" in the trade were more likely to be second income generators (86%; n = 6/7), whereas "hunters" were more likely to be second- or third-income generators (90%; n = 18/20). Likewise, the majority of "bushmeat sellers" who responded (57%; n = 8/14) were second- or third-income generators. Chi-squared tests of association revealed no significant association between "place as income generator" and gender, education, or religion.

Trade dynamics: Ball python hunters

When asked where (geographically) they hunt ball pythons, all of those who responded (n = 24) stated in Benin with the vast majority stating in the south of Benin (83%; n = 20). The remaining either stated in all regions of Benin (n = 2), the centre of Benin (n = 1), or the north of Benin (n = 1). When asked the habitat types from which they hunt ball pythons, 27 people responded. All reported hunting ball pythons from a mixture of "croplands" (i.e., cultivated fields), "fallows" (i.e., fields that are normally cultivated but are left so that soil fertility can regenerate) and "forests" (i.e., areas domi-

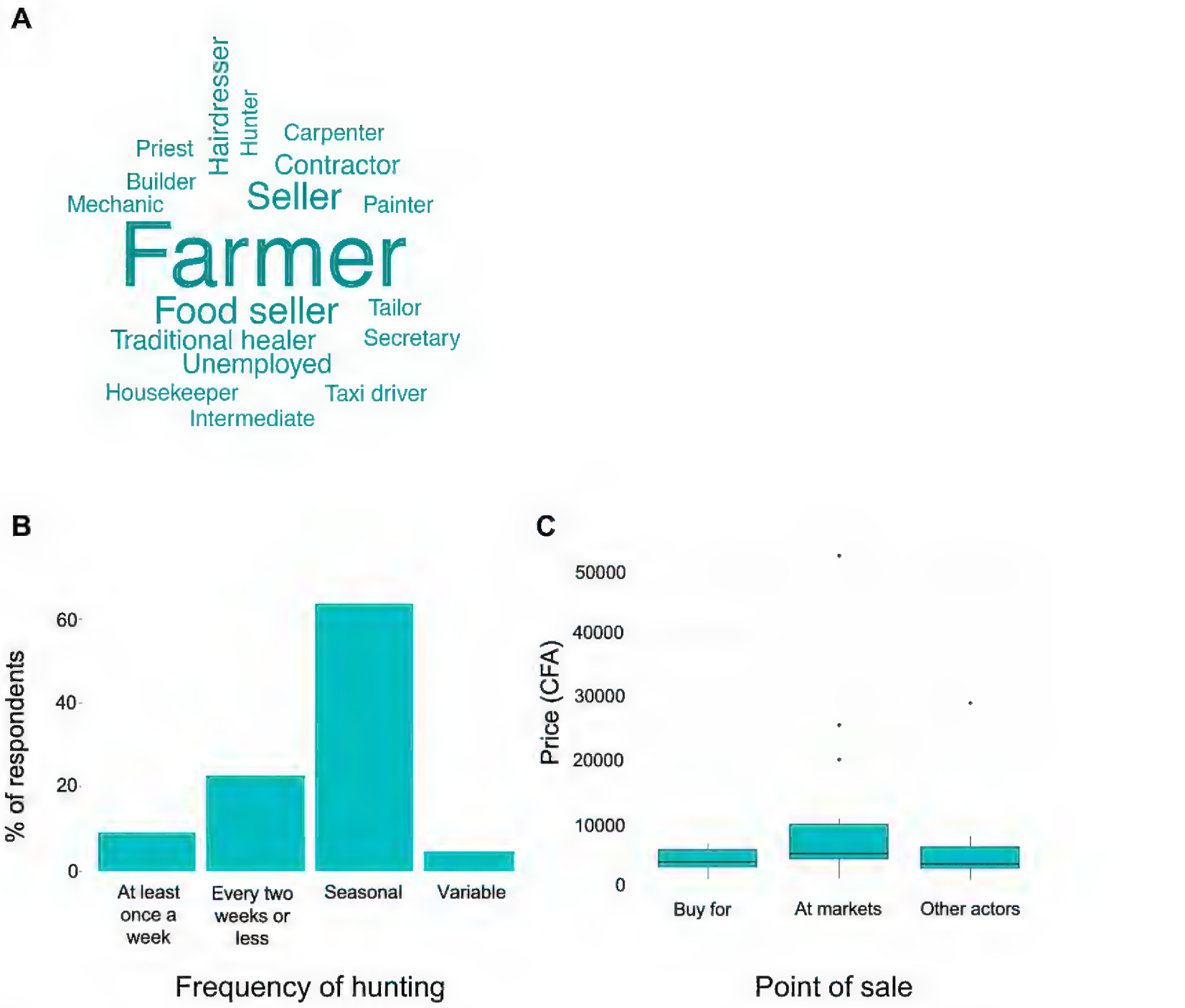

Figure 2. A Word cloud depicting reported primary professions of people involved in the ball python trade (n = 41), where font size is proportional to the number of participants **B** reported frequency of hunting ball pythons as a percentage of responses to the question (n = 19) **C** reported purchase/sale price of ball python [per specimen (i.e. either alive, dried, as a whole or in parts)] either bought, sold at bushmeat-markets, or sold to other buyers in the trade chain (n = 58, participants could give more than one answer).

nated by trees forming a canopy). Four participants added "villages" (i.e., habitat adjacent to or bordering villages).

When asked how often they hunt ball pythons, 19 people responded. Hunting took place year-round, but the precise timing and frequency was variable (Fig. 2B). The most frequent response was "seasonal" (63%; n = 15; Fig. 2B) which either meant during the "hunting season" (26%; n = 5) (which predominantly takes place between January and April), the "dry season" (21%; n = 4) (which takes place from December to March/April), or the "rainy season" (16%; n = 3) (from April to late July). The number of ball pythons reportedly collected per hunting trip ranged between 0 and

15 (mean = 4.8, SD = 2.8) (Table 2). No significant association was found between the frequency of ball python hunting (see Fig. 2B for categories) and role in the trade ($p > 0.6$).

A total of 21 participants reported information on their hunting activities from which an annual hunting rate could be estimated [Definition 1]. Based on the reported information, we estimate that these 21 participants each hunt on average 129 ball pythons annually (SD = 282.4, range = 0 to 1,200) (Table 2), and a collective average of 2,832 ball pythons each year [Definition 2] (total range = 576 to 5,083). Hunters had been involved in hunting ball pythons from one to 51 years (mean = 14; SD = 12.3 years, n = 19), and almost half (47%) of those that responded to the question had been hunting for between 10 and 29 years.

Trade dynamics: Ball python buyers

When asked for additional details regarding the buying of ball pythons, 14 people responded. Buying of ball pythons was a year-round activity but at variable frequencies: two participants stated that they bought ball pythons "weekly", two stated "twice yearly", others stated either "monthly", "every hunting season", or "every three days" (n = 1, respectively). Four participants provided answers without a specific time frame or that were otherwise unclear. The reported price paid per specimen by buyers averaged 4,178 CFA (7.5 USD; SD = 1,749) but varied between 500 CFA (0.9 USD) and 12,000 CFA (21.5 USD), presumably dependent on the precise product purchased (i.e., a live or dried snake, as a whole or in parts, Fig. 2C). Data on specific products

Table 2. Summary of reported number of ball pythons hunted per hunting trip/year, number of ball pythons purchased per trip/year, and the number of ball pythons sold at bushmeat markets and to other buyers per day/year (SD in brackets). n = the number of survey respondents that answered the question.

Trade stage	Variable	Absolute min.	Average min.	Overall average	Average max.	Absolute max.
Ball python hunting	Ball pythons hunted per hunter per hunting trip	0	2.9 (2.8)	4.75 (2.8)	6.5 (3.9)	15
	Ball pythons hunted per hunter per year [Definition 1]	0	26.2 (44.9)	128.7 (282.5)	221 (531.8)	1,200
Ball pythons purchased (n = 8)	Ball pythons purchased per buying trip	1	11.1 (12.9)	13.9 (17.3)	16.8 (21.6)	50
	Ball pythons purchased per year [Definition 3]	10	82.3 (97.2)	95.4 (125.6)	108.5 (155.1)	480
Ball pythons sold at bushmeat markets (n = 9)	At bushmeat markets (per day)	1	21.1 (33.6)	27.8 (43.5)	34.6 (53.7)	150
	At bushmeat markets (per year) [Definition 4]	20	307.7 (405.5)	366.3 (492.6)	424.9 (586.6)	1,800
Ball pythons sold to other buyers (n = 6)	To other buyers (per time)	1	12.5 (10.8)	15.8 (15.6)	19.2 (20.8)	50
	To other buyers (per year)	15	109.3 (106.7)	126.4 (138.3)	143.5 (171.7)	480

purchased were not available. Of the eight participants that provided a specific time frame for when they buy ball pythons (e.g., weekly, monthly), the number of snakes purchased per buying trip averaged 14 (SD = 12.9) but could be as high as 50 and as low as one specimen (Table 2). Based on the reported information, we estimate that these eight participants each purchase on average 95 (SD = 125.6) ball pythons annually [Definition 3], suggesting a total of 658 to 868 ball pythons bought each year in total. Four of these participants provided information regarding the number of years that they had been buying ball pythons. Most (75%) had been buying ball pythons for two to three years, but one had been buying them for 23 years.

Trade dynamics: Market sellers

When asked for additional details regarding the sale of ball pythons at local bushmeat markets, 23 people responded. When asked the location of the markets, most participants who answered this question (75%; n = 15/20) reported selling ball pythons at markets in Benin only, two participants sold them at markets in Nigeria only, one participant sold them at markets in Benin and Togo, one stated at markets in Benin and Nigeria, and one stated at markets in Togo and Nigeria. When asked who their clients were in the markets, the vast majority (87%; n = 13) stated "traditional healers", two thirds (60%; n = 9) stated "private consumers", a third (33%; n = 5) stated "middlemen", two stated "hotel/restaurant tenants" and one stated "villagers". Three participants did not know the nature of their consumer. Of the four participants that sold to bushmeat markets in Nigeria, the snakes were sold to "traditional healers" (n = 3 participants), "hotel/restaurant tenants" (n = 2), "private consumers" (n = 3) and "intermediates" (n = 1).

When asked how often they sell ball pythons at bushmeat markets, 17 people responded. Selling of ball pythons was a year-round activity but at variable frequencies: a quarter (24%; n = 4) stated "daily", 18% (n = 3) stated "at least once a week", two stated "twice per year", one stated "per season", and one stated "at least once per month". A third (35%; n = 6) provided answers without a specific time frame or that were otherwise unclear. Of those that provided a specific time frame for when they sell ball pythons at bushmeat markets, the number of ball pythons sold per day averaged 28 (SD = 43.5) but ranged between 1 and 150 specimens (Table 2). Based on the reported information, we estimate that the number of ball pythons sold by each participant at bushmeat markets annually is on average 366 (SD = 492.6; range = 20 - 1,800) [Definition 4], with between 2,749 and 3,734 ball pythons sold in total each year. The reported price snakes were sold for at markets [per specimen (i.e., either alive, dried, as a whole or in parts)] averaged 9,459 CFA (17 USD) but varied (SD = 11,273) between 600 CFA (1.1 USD) and 100,000 CFA (179 USD) (Fig. 2C). Seven of these participants provided information regarding the number of years that they had been selling ball pythons at markets, which ranged between two to 20 years (mean = 10.3 years; SD = 7.2). Ten traders provided information on both buying prices and sales prices at local markets, from which median profits per specimen from sales at markets were estimated at 3,500 CFA (5.4 USD) (Table 3).

Table 3. Summary of profits* from ball python trading in Benin, estimated from reported information from traders who both buy and sell ball pythons (a) at local markets (n = 10) and (b) to other buyers (n = 4). Profit are shown in CFA.

Role in the ball python trade	Market sales Mean profit	Min. profit	Max. profit
Middleman	20,250	-9,000	49,500
Middleman	47,000	-5,000	99,000
Bushmeat seller	4,000	-11,000	19,000
Bushmeat seller	5,000	-9,000	19,000
Exporter	50	-900	1,000
Exporter	0	-3,000	3,000
Multiple	17,000	13,000	21,000
Bushmeat seller	3,000	3,000	3,000
Bushmeat seller	2,500	2,500	2,500
Bushmeat seller	1,500	1,500	1,500
Role in the ball python trade	**Other Buyer sales Mean profit**	**Min. profit**	**Max. profit**
Middleman	22,750	17,000	28,500
Middleman	22,750	17,000	28,500
Bushmeat seller	-1,000	-3,250	1,250
Middleman	-600	-2,750	1,550

*Traders reported a range of values for buying and selling prices per specimen. From this we estimated the maximum profits per specimen sold as the minimum price paid per specimen minus the maximum price specimens were sold for, and the minimum profits as the maximum price paid per specimen minus the minimum price specimens were sold for. We calculated the "average" prices as the midpoint between the range values reported. "Average" profits were then estimated as the "average" price paid per specimen minus the "average" price sold for per specimen. Note that these values are only indicative and may not be realistic as the traders did not report the type of ball python specimen (e.g., live, smoked, dried, etc.) bought or sold and therefore the type of specimen sold/bought may be variable. Note also that our estimated minimum and maximum profits represent theoretical extremes - these may not occur in reality, and therefore negative values shown in the table do not necessarily mean that sellers ever make a loss; likewise, estimated maximum profits may be over-estimated.

Trade dynamics: Sellers (other buyers)

When asked for additional details regarding the sale of ball pythons to other buyers, 17 people responded. When asked about the location of the buyers they sold ball pythons to, half of those who responded (50%; n = 8/16) reported selling them to other buyers located only in Benin, a third (31%; n = 5) stated Nigeria, one stated Togo and Nigeria, and one stated "variable" locations. When asked what ball pythons were sold to other buyers for, the majority of those who answered (64%; n = 9/14) did not know, a quarter (n = 4) stated that they were purchased for "medicine", and one stated for "food". Of those that sold to other buyers in Nigeria (n = 6), three of these buyers were purchasing for "medicinal use" (the nature of the other three buyers was unknown).

When asked how often they sell ball pythons to other buyers, most participants who answered (63%; n = 10/16) provided answers without a specific frequency or that were otherwise unclear. The remaining six participants provided responses that were year-round with variable frequencies [e.g., "every season" (n = 2), "approximately once per month", "two times per month", "three times per month", or "at least once a week" (n = 1 respectively)]. The average number of snakes sold to other buyers annually [Definition 5] was 126 (SD = 138.3) but ranged from as little as one to as many

as 480 (Table 2). The reported selling price per snake (per specimen i.e., either alive, dried, as a whole or in parts) to other buyers was also variable, averaging 6,784 CFA (SD = 8,089; 12.2 USD) and ranging from 500 CFA (0.9 USD) to 29,000 CFA (52 USD) (Fig. 2C). Four traders provided information on both buying prices and sales prices to other buyers, from which median profits per specimen were estimated at 11,075 CFA (17.2 USD) (Table 3). We were unable to detect a statistically significant difference in the mean price sold for at bushmeat markets or to other actors (Welch's t-test: t = 0.9436, df = 37.58, p-value = 0.3514) or point of sale (price bought for, price sold for at bushmeat markets, price sold for to other buyers; Kruskal-Wallis chi-squared = 3.5731, df = 2, p = 0.17). Presumably this is due to the high variability in reported prices at each point (which may reflect true variability in value but may also arise from differences in respondent definitions of "products" sold and uncertainty as to whether prices sold for refer to price per snake or price per "part" of a snake).

Participant perceptions of the trade

When asked about what ball pythons represent to them (i.e., what purpose they are sold for), 32 people responded. Two thirds (59%; n = 19) stated "income", 53% (n = 17) stated "bushmeat", and 39% (n = 17) referred to belief-based use ["fetish" (n = 9), "medicinal products" (n = 4), "voodoo" (n = 4); Fig. 3]. Note that it is presumed that "bushmeat" and "belief-based use" could also represent income for some of these traders. There was no statistically significant association between the purpose snakes are sold for and the participants' role in the snake trade ($p > 0.05$), the religion they practise ($p = 0.87$), or their ethnic group ($p = 0.43$). When asked if the snake trade was profitable, 38 people responded. Of these participants, 79% (n = 30) stated "yes", 16% (n = 6) responded that it was "moderately profitable", and only one participant answered "no" in this regard.

When asked what difficulties they experienced when trading ball pythons, 37 people responded. Most referred to difficulties related to finding specimens in the wild (35%; n = 13), with 16% specifically referring to rarity ["rarification" (n = 4) and "species rare" (n = 2)], 24% (n = 9) referred to trade regulations [i.e., "bans induced by species deification" (n = 2) and "enforcement via forest guards" (n = 7)], 19% (n = 7) referred to difficulties associated with "storing" the ball pythons (i.e., housing, maintaining and keeping of snakes), 11% (n = 4) referred to market-based challenges ["bad sales" (n = 3) and "low prices" (n = 1)], and two referred to "bush fires" (Fig. 4A). Only three (8%) participants stated that they experienced no challenges when trading ball pythons.

When asked about the population status of wild ball pythons, 38 people responded. All but one (97%; n = 37) stated that ball pythons were not as common as they were 30 to 40 years ago, and that there were fewer ball pythons compared to five years ago (Fig 4B). One participant stated that ball pythons were as common as they were 30–40 years ago and that populations had remained the same as five years ago.

When asked about the reasons for any perceived declines in ball pythons in the wild, 36 people responded. Nearly all participants (94%; n = 34) stated "hunting" as a reason, and two referred to "deforestation" (including general degradation of habitats) in this re-

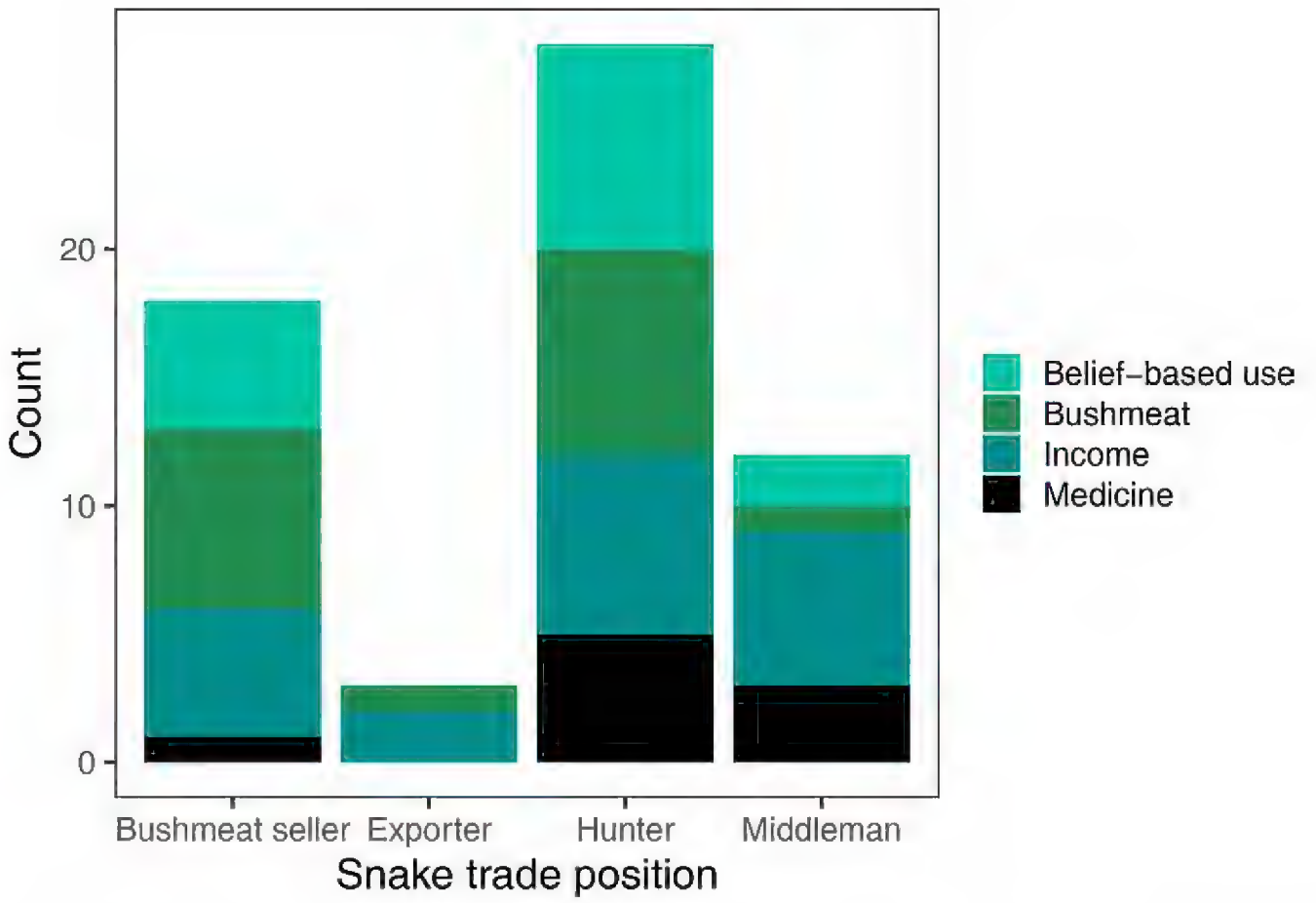

Figure 3. What ball pythons represent (i.e., what purposes they are sold for) to different actors in the trade chain. Note, participants could give more than one response.

gard. When asked about whether their own role in the snake trade was regulated, 33 people responded. Almost three quarters (73%; n = 24) stated that they did not think that their role was regulated (within national legislation) [with the remaining 27% (n = 9) stating that they thought it was], and there was no significant difference in response across trade roles (Fischer's exact test: p = 0.092). None of the participants were able to provide any written or otherwise documented records of their involvement in the ball python trade.

Discussion

Our study of ball python trade dynamics in Benin, West Africa, represents the first of its kind referring to the complexity of this trade for nearly 15 years (see Ineich 2006; Penner et al. 2008). The findings provide a unique insight into the dynamics and drivers associated with the ball python trade at a time of the year when hunters are not predominantly actively involved in supplying eggs, neonates, and gravid females to reptile facilities in Benin for ranching and international export as exotic pets. Our findings reveal a complex network of trade relationships and show that several different actors are involved in hunting, trading, and utilization of ball pythons in Benin. In Fig. 5 we show some of the linkages and overlap in the trade chain. For example, hunting of ball pythons from the wild is not only carried out by "hunters" but also "bushmeat sellers" and "middlemen" (who also source snakes by purchasing specimens from others). There are also different

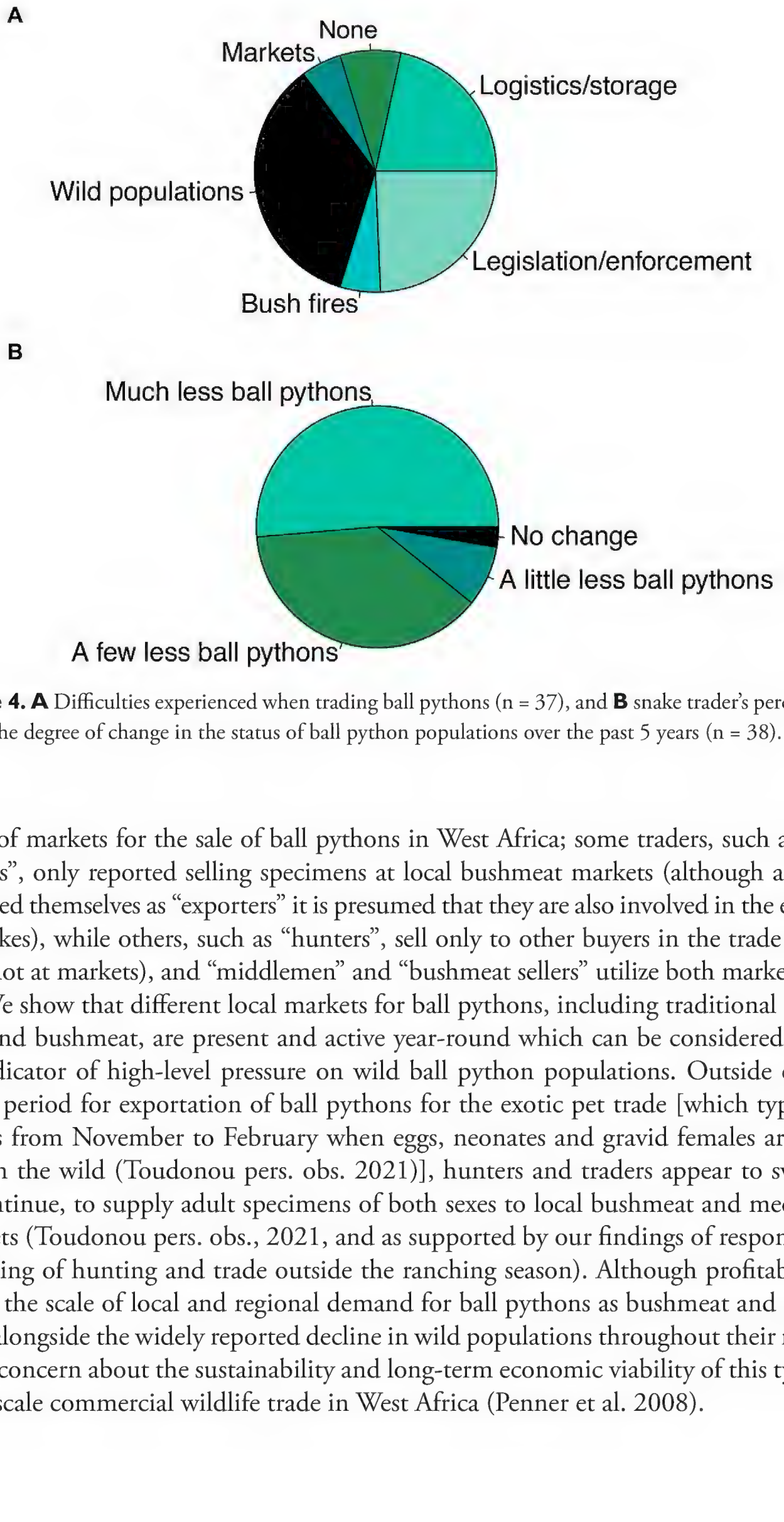

Figure 4. A Difficulties experienced when trading ball pythons (n = 37), and **B** snake trader's perception about the degree of change in the status of ball python populations over the past 5 years (n = 38).

types of markets for the sale of ball pythons in West Africa; some traders, such as "exporters", only reported selling specimens at local bushmeat markets (although as they reported themselves as "exporters" it is presumed that they are also involved in the export of snakes), while others, such as "hunters", sell only to other buyers in the trade chain (i.e., not at markets), and "middlemen" and "bushmeat sellers" utilize both markets.

We show that different local markets for ball pythons, including traditional medicine and bushmeat, are present and active year-round which can be considered to be an indicator of high-level pressure on wild ball python populations. Outside of the active period for exportation of ball pythons for the exotic pet trade [which typically occurs from November to February when eggs, neonates and gravid females are present in the wild (Toudonou pers. obs. 2021)], hunters and traders appear to switch, or continue, to supply adult specimens of both sexes to local bushmeat and medicine markets (Toudonou pers. obs., 2021, and as supported by our findings of respondents reporting of hunting and trade outside the ranching season). Although profitable for some, the scale of local and regional demand for ball pythons as bushmeat and medicine, alongside the widely reported decline in wild populations throughout their range, raises concern about the sustainability and long-term economic viability of this type of large-scale commercial wildlife trade in West Africa (Penner et al. 2008).

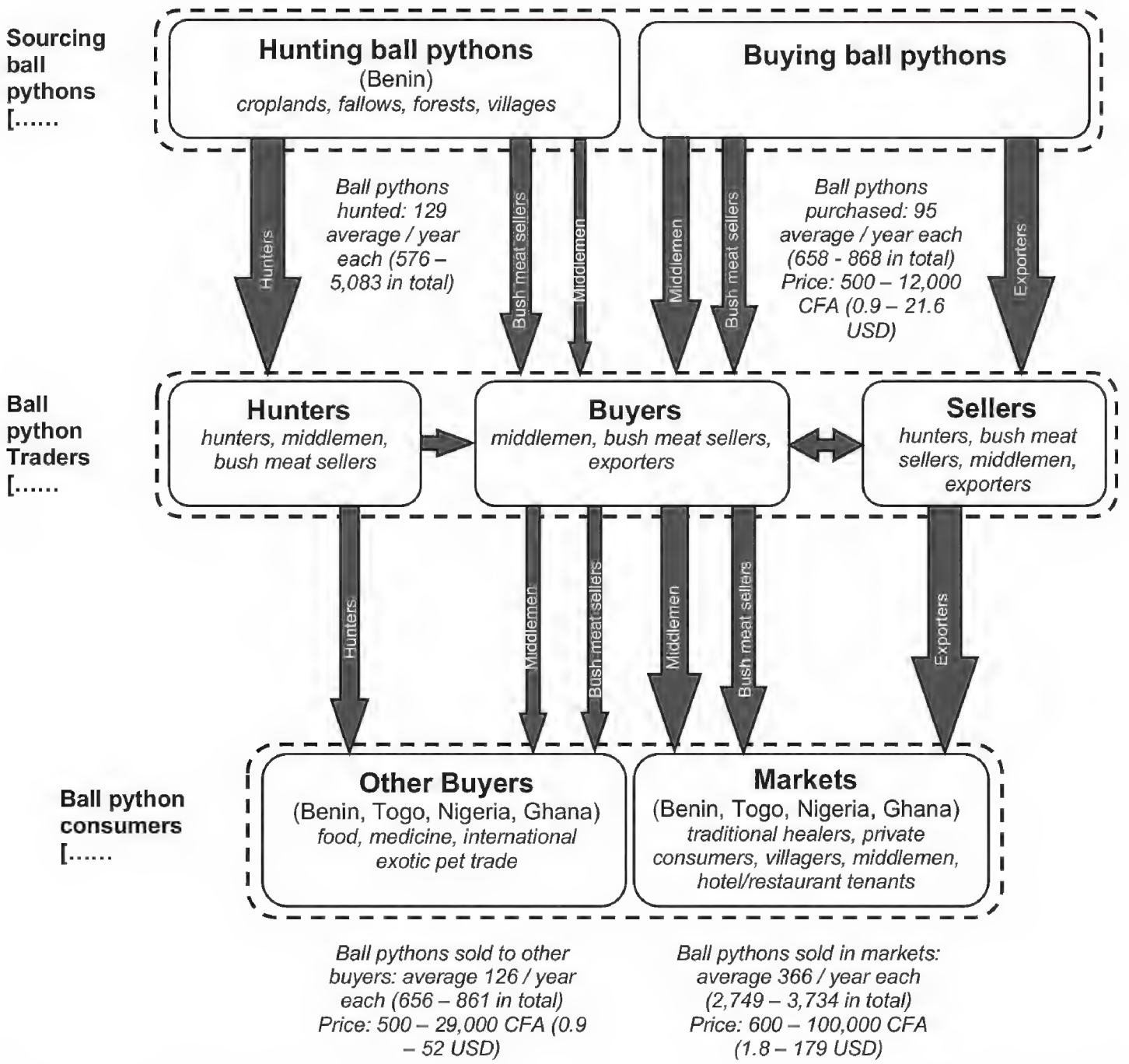
Sourcing ball pythons [.....
Hunting ball pythons
(Benin)
croplands, fallows, forests, villages
Buying ball pythons
Hunters
Ball pythons hunted: 129 average / year each (576 – 5,083 in total)
Bush meat sellers
Middlemen
Middlemen
Bush meat sellers
Ball pythons purchased: 95 average / year each (658 - 868 in total) Price: 500 – 12,000 CFA (0.9 – 21.6 USD)
Exporters
Ball python Traders [.....
Hunters
hunters, middlemen, bush meat sellers
Buyers
middlemen, bush meat sellers, exporters
Sellers
hunters, bush meat sellers, middlemen, exporters
Hunters
Middlemen
Bush meat sellers
Middlemen
Bush meat sellers
Exporters
Ball python consumers [.....
Other Buyers
(Benin, Togo, Nigeria, Ghana)
food, medicine, international exotic pet trade
Markets
(Benin, Togo, Nigeria, Ghana)
traditional healers, private consumers, villagers, middlemen, hotel/restaurant tenants
Ball pythons sold to other buyers: average 126 / year each (656 – 861 in total) Price: 500 – 29,000 CFA (0.9 – 52 USD)
Ball pythons sold in markets: average 366 / year each (2,749 – 3,734 in total) Price: 600 – 100,000 CFA (1.8 – 179 USD)

Figure 5. Ball python (*Python regius*) trade chain in Benin, West Africa. The numbers presented refer to specimens (i.e., either alive, dried, smoked, as a whole or in parts). The width of the arrow indicates the relative proportion of the different actors that are involved in the varying/diverse trading activities including "hunters" (n = 18), "bushmeat sellers" (n = 14), "middlemen" (n = 8), "exporters" (n = 2).

Ball python trade dynamics

Those who self-identified as "hunters" in our study, along with many (62%) "bushmeat sellers" and, to a lesser extent (33%), "middlemen" reported that they engage directly in ball python hunting, and some had been hunting pythons for up to 51 years. We estimate that the traders engaged in hunting (n = 21) collectively hunt between 576 and 5,083 ball pythons from the wild each year (Fig. 5). It is likely that capture success is determined in part by the number of people involved in each hunting trip (D'Cruze et al. 2020a). Most individual hunters are reportedly active on a "seasonal" basis, either during the "hunting season", "dry season" or "wet season". Unlike hunting for ranching, where for example in Togo it is reported that hunters predominantly

Figure 6. Varying commodities of ball pythons (*Python regius*) **A** "Leucistic morph" at a snake farm in Benin intended for the international exotic pet trade **B** sold as bushmeat at a local market in Benin **C** at a snake farm in Benin intended for the international exotic pet trade **D** desiccated carcasses sold for belief-based use at a market in Benin. Neil D'Cruze / World Animal Protection.

collect pythons between the months of January to April to supply reptile facilities for international export (D'Cruze et al. 2020a), it appears hunting for traditional medicine and bushmeat can occur at any time of the year (i.e., there is no particular season), most likely because adult life stages are predominantly targeted. Further research is needed to determine the extent of hunting of ball pythons taking place in Togo for other markets outside of the active exotic pet period.

Our findings indicate that ball python trade is an important source of income for many of those involved; when asked, around 80% of 38 traders in our study stated that it was a "profitable" endeavor (see also Table 3). However, for many, it appears to

provide a secondary source of income, as most traders (84%) interviewed in our study engaged in a wide range of alternative, primary professions (Fig. 3). Consequently, more information on the relative importance of ball python trade as a supplementary source of income would likely prove valuable to aid future conservation focused policy decision-making and the need for alternative livelihoods. Interestingly, over a third of traders stated "farming" as their primary source of income, which is unsurprising given that croplands and fallows are widely reported as suitable sites for hunting ball pythons. We did not specifically set out to understand if "hunting" was passive or active in the study (i.e., the extent to which "farmers" see a snake and collect it as they go about their farming practices or whether they actively take periods of time dedicated to "hunting" the snakes, such as when income from crop yields is lower). However, this could be an important question to explore further. For example, it might explain why ball python hunting is more of a year-round activity in Benin overall (albeit individual hunters tend to hunt on a "seasonal" basis, the timing of which can vary between hunters), where more than 70% of the population is economically dependent on agriculture (USGS 2021) (i.e., it could be the case that pythons are opportunistically harvested in agricultural areas). Our findings also indicate that the ball python trade is more lucrative for the relatively few actors further up the trade chain. For example, "bushmeat sellers" and "hunters" were more likely to be second-or-third income generators in their household, whereas "middlemen" were more likely to be second income generators, and [whilst acknowledging the relatively small number of participants (n = 2)] all the "exporters" involved in the international exotic pet trade interviewed were identified as primary income generators.

Although we found no statistically significant difference in the mean price paid for ball pythons at point of sale, maximum reported prices suggest that the sale of pythons at bushmeat markets (either alive, dried or smoked specimens) may be more financially lucrative than sales to other buyers: the maximum reported sale price per python/specimen was over three times higher when sold at bushmeat markets than when sold to other buyers. However, more data on the factors that influence price is required, such as in relation to the type of specimen sold (e.g., alive, dried, smoked).

Collection rates reported by some hunters from Benin suggest that they can earn much more from python sales at bushmeat markets [up to nine million CFA (approximately 15,500 USD), estimated as the maximum specimens sold at markets per day × number of selling days per year × maximum price per specimen sold)] compared to income generated from cash crops [which could be up to two million CFA (SalaryExplorer, 2022)], for example. This income is marginally higher than reported in Togo in 2019, where the sale of live ball pythons was estimated to generate a maximum annual income per hunting party (average of five hunters) of 24 million CFA (approximately USD 41,000) (D'Cruze et al. 2020a). Harvesting rates are also very similar to those observed in Togo where hunters each collect an estimated 120 live ball pythons annually, predominantly to supply "ranching" operations for the international exotic pet market (D'Cruze et al. 2020a). Like hunting, buying and selling of ball pythons also appears to be a year-round activity in West Africa.

Drivers of the ball python trade

According to the hunters interviewed in our study, ball pythons are mainly sold to local customers in Benin as "bushmeat" or for belief-based uses (including "fetish" and "voodoo"), and to traditional healers. However, our findings clearly highlight the dynamics of regional cross-border trade that occurs with the neighboring countries of Togo, Nigeria, and Ghana. For example, a third of traders in our study reportedly sold ball pythons to buyers in Nigeria. Notably, some cross-border markets, such as Badagry in Nigeria, are reported as being more favorable for selling ball pythons because both the demand and prices are higher (Toudonou pers. obs. 2021), and therefore trade is more profitable. In addition, our preliminary survey in 2007 indicated that pythons for the bushmeat market are sold as far afield as Cameroon.

The regional nature of this commercial wildlife trade in West Africa has been documented in previous studies in other range states. Ineich (2006), for example, reported that ball pythons hunted in Benin are legally and illegally transported to Ghana. Informal, and potentially illegal, cross-border trade of ball pythons for the bushmeat and traditional medicine markets has also previously been documented between Togo, and Benin and Nigeria (Eniang et al. 2006; Toudonou 2015; D'Cruze et al. 2020c; Harrington et al. 2020). Specifically, links between registered ball python exporters in Benin and the Badagry bushmeat market in Nigeria have previously been reported (Toudonou 2015), and it has been suggested that a negative association exists between the volume and numbers of ball pythons sold as bushmeat and the active season for exotic pet exportations (i.e., more snakes were sold at the market when fewer were exported as pets). However, while these other range states are mentioned as consumers of pythons hunted in Benin, it appears that Beninese hunters only source snakes within their own national borders. This is in contrast to findings from Togo (D'Cruze et al. 2020a), where it was reported that a large proportion of hunters and traders source ball pythons outside of Togo, including from Benin, with some also selling snakes back to ranching facilities in Benin and Ghana.

Our findings indicate that the exotic pet market is not always the main driver of ball python trading in West Africa. During the months of August to October, snakes were primarily reported to be traded for bushmeat and medicines and only few traders surveyed self-described as exotic pet "exporters". Given that snake farms are exporting ranched snakes for the exotic pet trade (D'Cruze et al. 2020a; Harrington et al. 2020), it is presumed that some of the participants surveyed in our study may switch and or continue in supplying medicine and bushmeat markets when they are not actively involved in hunting eggs and gravid females for the exotic pet trade. Further research into temporal changes in ball python hunting activities and the links between the different trades (exotic pets, bushmeat, and medicine) would aid future conservation focused decision making. In particular, although policy actions have already been taken in Benin to limit pressure on the species caused by high international demand (such as a more severe reduction in annual CITES quotas in comparison to Togo and Ghana), more research carried out at the peak of the exotic pet trade in Benin [similar to that done in Togo (Harrington et al. 2020)], would help to determine the volume of

snakes hunted for this type of trade. Furthermore, future conservation actions should consider the different types of trade that occur at national, regional and international levels. Difference in cultures, beliefs and preferences mean that attitudes and behaviors toward the consumption of ball pythons vary among areas and tribes in West Africa, and that could also play a factor in the dynamics of trade at a local scale. In the case of Nigeria there is demand for snakes as food and for belief-based medicine among some communities and tribes (Ijeomah et al. 2017), and this could explain why ball pythons are targeted for these markets in our study.

Regulation of the ball python trade

In Benin a license is required by Law No. 2002–16 (2004) to legally harvest, market or export "partially protected species" (which includes ball pythons), whether for personal or commercial purposes. Similarly, collection of the eggs of partially protected species is also permitted on a limited basis. However, under Article 154, it is an offense to hunt gravid females or juveniles. Moreover, since females and juveniles of partially protected species should be treated as fully protected species (Article 33), Article 36 also suggests that these animals should not be kept (except under exceptional cases for scientific purposes). However, 73% of survey participants, regardless of their role in the trade, stated that they did not think their activities were regulated, suggesting that the hunting and trade of ball pythons is weakly enforced. Further, the estimated number of ball pythons harvested from the wild each year by the hunters interviewed in our study alone (500 - > 5,000 specimens) exceeds the total numbers permitted for export by CITES (200 specimens), suggesting that domestic use adds considerably to offtake pressure permitted for export. In addition, it is possible that some of the live snakes that are reportedly sold to actors in bordering countries (e.g., Togo, Ghana) were destined for wider international export as exotic pets, as a way to circumvent the relatively limited trade quota in Benin. In Togo, for example, the agreed CITES export quotas are currently several times higher (1,500 wild-caught ball pythons and 62,500 ranched ball pythons, respectively, UNEP 2021) than in Benin.

Implications of the ball python trade

Our findings highlight conservation concerns associated with this type of trade in West Africa, given that ball pythons are now listed as Near Threatened on the IUCN Red List due in part to high exploitation levels (D'Cruze et al. 2021). The high number of ball pythons hunted and traded each year raises questions about the sustainability of the trade and thus to what degree its impact is detrimental to wild populations. Although the species is relatively widely distributed in West Africa, and reflects some adaptability to anthropogenically-altered habitat-systems, the heavy and persistent targeting of ball pythons for meat, exotic pets, leather and for belief-based use (Segniagbeto et al. 2013; D'Cruze et al. 2020c, 2021) has resulted in declines of wild populations now reported in most range states (Reading et al. 2010).

Harvesting pressure is exacerbated by severe habitat modification due to natural and human causes including agricultural expansion and increasing drought frequency (Reading et al. 2010, USGS 2021). Furthermore, indications are that on-going "ranching" operations like those in Benin and Togo, which are thought to provide some protection for the species (Ineich 2006), are negatively impacting wild populations due to the methods employed which include unsustainable collection of wild specimens to maintain ranch stock, the targeting of the most vulnerable biological stages for wild collection, destruction of burrows during harvesting, and potential for genetic pollution of local wild subpopulations through unregulated release of captive born stock (Auliya et al. 2020; D'Cruze et al. 2020a). While demand for the international exotic pet trade has been cited as the primary threat to the survival of wild ball python populations over recent decades, the high harvesting rates (outside of the active period for live CITES exportations) observed in our study may reflect a potentially increasing threat to the species caused by other aforementioned regional demands. Similar increasing demands for frog meat in West Africa have been observed, predominantly for the African tiger frog (*Hoplobatrachus occipitalis*). In this case, extensive cross-border trade in wild-caught specimens is taking place in Benin and Nigeria, mostly to supply Nigerian bushmeat markets, with potentially detrimental consequences for wild frog populations (Mohneke et al. 2010).

Effective management of the ball python trade, and its associated impacts on wild populations, is hindered by the fact that information is lacking on the distribution, population trends and genetic structure of the species for much of its range in West Africa. For example, formal population monitoring of the species is lacking on the ground (D'Cruze et al. 2021) making it impossible to assess whether or not trade is sustainable. However, indications from trader perceptions of the status of wild populations suggest that the current level of exploitation is unsustainable. Most of the traders interviewed in our study stated that the species is not as common as it was 30–40 years ago, with half of these traders believing that populations of ball pythons were "much lower" today. Moreover, a high percentage of traders cited "hunting" as the cause of the perceived decline in ball python numbers.

Study limitations

The data derived from interviews with hunters and traders in this study should be interpreted with some care. Like with any wildlife trade survey that touches upon aspects related to unsustainable exploitation, it is possible that participants may prove unreliable or have poor memory recall (Newing et al. 2011). For example, participants may not have reported the true magnitude or value of ball python trading and hunting activities, meaning that our data may underestimate or overestimate trading levels and the impact on ball pythons. Furthermore, in extrapolating the volume of ball pythons hunted, bought and sold at a specific timeframe to annual rates, we may have over- or under-estimated the true numbers (either overall, or the relative proportions for particular purposes). However, the similarity in our data when compared to ball python hunter surveys in other range states (D'Cruze et al. 2020a) is a good indication

of the validity of our findings. We provide updated data on the national/regional trade of ball pythons, which mainly illustrate the complexity of the trade and of the different players within the trade chain. This study should be extended with regard to certain detailed questions, such as on temporal and seasonal changes in the purpose and volume of ball pythons traded, and variation in income from trade across the different points of sale. Moreover, it is important to note that our aim was not to assess the full extent of hunting and trading activities in this part of West Africa, the impact on ball pythons, or the total number of hunters and traders involved. Instead, we aimed to provide a "snap-shot" of trading activity, at one time of the year where the main focus is not on the exotic pet trade, to understand the activities undertaken by traders and hunters so we can assess additional potential factors that might warrant further research. We believe that our "snap-shot" survey approach has provided findings that present valuable information that can be used to inform future efforts to sustain viable populations of ball pythons throughout West Africa.

Recommendations

The current lack of data on the status of wild ball python populations is resulting in uncertainty for the long-term sustainability of the ball python trade. Given that legality does not necessarily imply sustainability (Macdonald et al. 2021), and there is increasing recognition of the multiple threats unsustainable trade can have for local communities (IPBES 2019), this type of data is needed to inform better regulatory measures to protect both ball pythons and people and should be prioritized (Harrington et al. 2020). At a domestic and regional level, the trade is characterized by high harvesting rates and unregulated and potentially unsustainable ball python consumption as bushmeat and belief-based use, with associated implications for local livelihoods and well-being. It is possible that commercial bushmeat and medicine markets may have been stimulated by the economic and commercial incentives generated by the exotic pet trade over the past few decades in Benin; however, this is an unknown aspect that warrants further investigation. In addition, further strategic decisions regarding the need for improved national and regional trade regulation requires both careful consideration and rapid action to safeguard wild populations. Moreover, existing and future domestic regulatory measures (e.g., licensing, quota systems, or trade bans) should also consider the need for awareness raising campaigns to ensure that those involved in the ball python trade are adequately apprised of any legal ramifications. Further, given that ball python trading is a valuable, albeit often secondary, source of income, initiatives to help hunters and traders find new, sustainable, alternative forms of income may also be required.

From an international trade perspective, it is not clear whether the reduction in live ball python quotas and exports from Benin for the exotic pet trade was a pre-emptive conservation strategy, a consequence of declining wild ball python populations caused by overexploitation, or alternatively, due to lower international consumer demand as this species for many years has been routinely bred in captivity, especially at some key markets in the USA and the EU (e.g., Barker and Barker 2006; McCurley 2007; Kölpin

2007; Broghammer 2013). Regardless, as a minimum policy measure, we recommend a similar reduction in legal live ranched export quotas in neighboring range states (Togo and Ghana) to limit adverse consequences for wild populations throughout the range states of ball pythons in the West African region. The legal situation in Benin needs juridical clarification and existing laws should be enforced. Lastly, in light of the cross-border trade activity highlighted in our study and others (Eniang et al. 2006; Harrington et al. 2020) we reiterate the need for a common multilateral agreement between the key range states that are predominantly involved in the commercial exploitation of ball pythons (Benin, Ghana, Nigeria and Togo) in order to effectively regulate trade.

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Supplementary material 1

Ball python trade questionnaire, Benin

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Data type: Questionnaire.

Explanation note: Questionnaire survey instrument.

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